Apparatus and method for measuring the weight of an optical

fiber preform during a chemical deposition process for

forming the preform

DESCRIPTION

5   The present invention refers to an apparatus and method for
measuring the weight of a preform for optical fibres during
a chemical deposition process for the formation of the
preform.

As is known, the most common processes for manufacturing
10   preforms for optical fibres foresee one or more chemical
deposition steps, through one or more burners, of suitable
chemical substances on a cylindrical support; the chemical
substances typically comprise silicon and germanium, which
are deposited in the form of oxides (SiO_2 and GeO_2). A
15   suction hood eliminates the discharge gases produced by the
burner.

Preform manufacturing process through chemical deposition
of the prior art comprise processes of the VAD type (Vapor
Axial Deposition), processes of the OVD type (Outside Vapor
20   Deposition) and processes of the MCVD type (Modified
Chemical Vapor Deposition).

Typically, in processes of the VAD type, the cylindrical
support is kept in vertical position through the use of a
clasping member acting upon an upper end of the cylindrical
25   support; the cylindrical support is made to rotate upon
itself so as to expose all of its surface to one or more
burners housed near to the lower end of the support and in
a position such as to emit a flow of reactants along a
direction inclined by a predetermined angle with respect to
30   the longitudinal axis of the support. The support is then
made to translate upwards so as to allow a substantially
axial growth of the preform.

In processes of the OVD type, on the other hand, the

cylindrical support is kept in horizontal or vertical position through the use of a pair of clasping members acting upon the opposite ends of the support; this support is made to rotate upon itself so as to expose all of its

5   surface to one or more burners laterally mounted with respect to the support and in a position such as to emit the flow of reactants along a direction substantially perpendicular to the longitudinal axis of the support. The burner, in particular, is mounted on a support structure

10   equipped with a motorised moving member which allows the repeated translation of the burner parallel to the cylindrical support, so as to allow a substantially radial growth of the preform along all of the sections of the support.

15   In processes of the MCVD type, the deposition is carried out on the inner surface of a tubular support made to rotate about its axis, again through the use of a burner translating parallel to the axis of the support itself.

For the sake of simplicity, in the rest of the present

20   description and in the subsequent claims explicit reference shall often be made to chemical deposition processes of the OVD type.

As is known, an important instrument for controlling and analysing the performance of the chemical deposition

25   process is given by the measurement of weight in time, and consequently of the deposition-rate, of the preform in formation during the chemical deposition process. The measurement of the weight of the preform, indeed, besides giving information on the rate and efficiency of the

30   chemical deposition in each of its steps, also gives advantages for the subsequent spinning steps of the optical fibre from the preform. The measurement of the weight also allows the value of the ratio between cladding/core masses to be worked out and controlled; knowing such a parameter

35   is essential for guaranteeing the optic transmissive

specification of the optical fibre spun from the preform.

Different devices for measuring the weight of a preform during a chemical deposition process for the formation of the preform are known.

5   JP06-329432 describes a chemical deposition process of the OVD type with horizontal configuration in which the preform is made to rotate about it own axis and is made to move horizontally above a fixed burner. A pair of opposite load cells measures the weight of the preform during the
10 chemical deposition process. In order to lessen errors in the measurement of the weight caused by thermal variations and by misalignment of the supports of the preform caused by the movement of the preform itself during the chemical deposition process, four different constructive solutions
15 are foreseen. A first solution foresees an alignment procedure carried out manually by an operator through adjustment of the supports of the base of the entire deposition machine. Checking of the alignment is obtained through an optical system consisting of a laser positioned
20 on one of the supports of the preform and of a detector of the position of the laser beam positioned on the other support. A second solution foresees measurement of the misalignment through two laser distance detectors positioned on the supports of the preform, which measure
25 its position with respect to two references; the adjustment is obtained through an automatic system which acts upon the supports of the deposition machine, such supports being suitably automated. A third solution foresees the elimination of the adjustment of the alignment of the
30 machine. In this case the system carries out a correction via software of the signal of the distance sensors which measure the alignment. The fourth solution foresees, besides the methods already quoted, a system for cooling the structure of the deposition machine to counteract the
35 thermal variations induced by the heat produced by the burner's flame. The temperature adjustment is obtained

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through a circuit equipped with a circulation pump crossed by demineralised water.

The Applicant observes that all of the solutions described above foresee the use of a system for measuring the
5   alignment of the supports of the preforms and have the aim of eliminating just the misalignment problems through manual adjustment, or software or through thermal adjustment of the entire base of the deposition machine. However, no system is foreseen for eliminating or lessening
10 other important sources of errors in the measurement of weight which shall be better described hereafter, like for example the thermal drift of the load cells (the effect of which is generally greater with respect to that of the expansion of the materials of the machine), the weight of
15 the systems for anchoring the preforms and of the systems for transmitting motion to the preform, the constraint reactions imparted by the hyperstatic characteristics of the system for anchoring the preform, the dynamic action of the forces which transmit motion to the preform, as well as
20 the dynamic actions linked for example to the rotation of the preform.

JP07-215725 described a chemical deposition process of the VAD type in which the preform, supported by an anchoring system, is made to rotate about its own axis and is moved
25 vertically through a preform-moving device. The measurement of the weight of the preform in formation is carried out through a weight sensor arranged between the mobile part of the preform anchoring system and the preform-moving system. To increase the precision in the measurement of weight,
30 between the mobile part of the preform anchoring system and the preform it is foreseen for there to be a mechanism of the active and passive type capable of absorbing the vibrations of the movement of the preform, such vibrations being the source of errors in the measurement of weight.
35 The Applicant observes that such a device is not capable of lessening the errors in the measurement of weight mentioned

above, like for example the thermal drift of the weight sensor, the forces transmitted by the anchoring system and system for transmitting motion to the preform and the dynamic actions of the systems for transmitting motion to
5   the preform.

Further devices for measuring the weight of a preform during a chemical deposition process for the formation of the preform are described in JP06-183772, EP-482348, JP02-167838, JP01-242435, JP63-285137, JP09-156946. The
10   Applicant observes that these still concern devices capable of carrying out a static measurement of the weight of the preform, and which therefore are subject to all of the errors in measurement mentioned above.

The Applicant has therefore specified a problem which is
15   common to devices of the known type. Such a problem is linked to the fact that to measure the weight of the preform systems apt to carrying out a static measurement of the weight are used, such as for example load cells or sensors. In such systems, in particular, the weight is
20   calculated by working out the vertical component of the forces acting upon the cells or sensors. The Applicant has verified that the measurement of the weight obtained through the use of load cells or sensors can be influences by various sources of errors, such as:

25   -   the drift of the signal caused by the heating of the load cells or sensors. Such a drift leads to high errors in measurement due to the non-uniformity of the thermal field which is realised on the cells. Such non-uniformity cannot always be eliminated through temperature compensation of
30   the conventional type;

-    the action, on the cells or on the sensors, of loads which are different from the weight of the preform in formation. Indeed, the load cells are affected, besides by the weight of the preform, also by other static and dynamic
35   types of force which it is not always possible to eliminate

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or quantify *a priori*. Static types of force typically comprise the weight of the preform anchoring systems, of the shafts and of the chucks associated with them, and of the systems for transmitting motion to the preform
5   (typically belt or gear systems). Dynamic types of force, on the other hand typically comprise the dynamic actions of the systems for transmitting motion to the preforms. Another type of dynamic action is the inertia of the motion of the preform itself.

10   The Applicant has found that by carrying out a dynamic measurement of the weight of a preform supported through at least one elastic constraint and subjected to oscillations during the chemical deposition process, and by detecting the frequency of oscillation of the preform as a rigid
15   body, it is possible to obtain a measurement of the weight of the preform which is substantially independent from the sources of error mentioned above, in particular the thermal drift of the measurement devices and the loads which are different from the mass of the preform the weight of which
20   one wishes to measure.

The frequency of oscillation is indeed directly linked to the oscillating mass; for example, for an axial oscillation, the frequency of oscillation ω is linked to the oscillating mass M by the following relationship:

25
$$M = \frac{k}{\omega^2}$$

where k is the elastic constant of the spring system; therefore, by knowing the frequency of oscillation and the elastic constant of the spring system one knows the oscillating mass, and therefore the weight.

30   The present invention therefore refers, in a first aspect thereof, to an apparatus for measuring the weight of a preform for optical fibres during a chemical deposition process for the formation of the preform, characterised in

that it comprises:
- at least one elastic constraint intended to be associated with at least one end portion of an elongated element constituting a chemical deposition substrate for
5   the formation of the preform;
- a device for inducing an oscillation on said elongated element;
- a device for detecting the frequency of oscillation of said elongated element;
10 - a device for calculating the weight of the preform according to the detected frequency of oscillation.

In the rest of the present description and in the subsequent claims indistinct use shall be made of the term "elongated element" or "cylindrical support" to indicate
15 the chemical deposition substrate from which, at the end of the deposition process, the preform is obtained.

In the rest of the present description and in the subsequent claims use shall also be made of the term "elastic constraint" to indicate any device for fixing the
20 preform to the frame of the chemical deposition machine, such a fixing device comprising at least one elastic element, such as spring, suitable for applying an elastic action.

Advantageously, the measurement of the weight carried out
25 through the apparatus of the present invention is a dynamic measurement and, as such, is not subject to the errors in measurement mentioned above with reference to the prior art.

Indeed, the measurement of the frequency of oscillation is
30 not affected by the thermal drift of the measurement devices since the elastic characteristics of the elastic elements, such as the springs, have a very low dependency upon the temperature.

Moreover, the measurement of the frequency of oscillation

can be made insensitive to the action of the variable loads, linked both to the transmission of motion to the preform and to the motion itself of the preform, sizing the measurement system so that such an action is applied at
5   frequencies far from that of the measurement system, which is therefore not influenced.

Moreover, the measurement of the frequency of oscillation is completely insensitive to the axial distribution of the masses.

10 The Applicant has also observed that the measurement of the frequency of oscillation is more sensitive to the mass deposited for low mass values, i.e. at the start of the chemical deposition process. This characteristic is particularly interesting for external deposition processes,
15 such as OVD or VAD; the yield and the deposition rate of such processes are indeed critical in the initial steps of the process due to the small size of the preform in formation. Advantageously, the measurement of frequency is therefore capable of providing detailed information on the
20 deposition process in its most critical steps.

Preferably, said at least one elastic constraint is a constraint with a single degree of freedom such as to allow an axial oscillation of said elongated element along its longitudinal axis X-X. Advantageously, since the frequency
25 of axial oscillation ω is linked to the oscillating mass M of the preform by the following relationship:

$$M = \frac{k}{\omega^2}$$

where k is the elastic constant of the elastic element, knowing the elastic constant of the elastic element and the
30 frequency of axial oscillation in time means that one knows the oscillating mass, and therefore the weight of the preform in formation. Since the above relationship is valid for an ideal harmonic oscillator, it is preferable, in the

case of a real oscillator, to carry out a calibration of the system with known masses so as to experimentally determine the relationship $M=M(\omega)$.

In alternative embodiments of the apparatus of the present
5   invention, other frequencies of oscillation of the rigid body can be used by realising any of the other manners of oscillation of a rigid body in one of its six degrees of freedom; in correspondence with the six degrees of freedom of a rigid body there are indeed three translational
10 manners of oscillation and three rotational manners of oscillation to which respective frequencies of oscillation correspond.

Preferably, said at least one elastic constraint comprises:
-   a first coupling element suitable for being rigidly
15 associated with a rotatable chuck;
-   a second coupling element suitable for being rigidly associated with said elongated element;
in which said first and second coupling elements are elastically and slidably coupled and are rotatably
20 constrained.

Advantageously, said at least one elastic constraint is therefore capable of:
-   preventing translations of the preform, with the exception of axial translation;
25 -   preventing the relative rotation between chuck and preform about the axis of said preform (so as to allow the transmission of the rotary motion from the chuck to the preform);
-   elastically constraining the axial translation of the
30 preform about a position of equilibrium to allow its axial oscillation.

Preferably, said at least one elastic constraint comprises a spring operatively placed between said first and second coupling elements. The elastic sliding coupling between
35 said coupling elements is thus realised.

Preferably, said first coupling element defines a first sleeve and said at least one elastic constraint also comprises a second sleeve rigidly associated with said at least one end portion of said elongated element and
5   coaxially mounted inside said first sleeve through the interposition of at least one bearing suitable for allowing a relative sliding between said first and second sleeves along said axis X-X. The axial oscillation of the preform along the axis X-X is therefore advantageously guided by a
10 sliding coupling between said first and second sleeves.

Preferably, the apparatus of the present invention also comprises a spherical joint placed between said second sleeve and said at least one end portion of said elongated element, to counter possible imprecisions of said elongated
15 element.

In a first alternative embodiment of the present invention, said at least one elastic constraint preferably comprises a pin associated with said first coupling element and coupled with a slot formed on said second coupling element. It is
20 therefore possible to realise the transmission of the rotary motion from chuck to the preform (through the first sleeve) and, at the same time, the axial oscillation of the preform.

In an alternative embodiment, the transmission of the
25 motion from the chuck to the preform is realised through a shape fitting between said second sleeve, rigidly coupled with the preform, and said first sleeve, rigidly coupled with the chuck. The shape fitting can be realised, for example, by foreseeing non-circular sections for the
30 conjugated surfaces of the two sleeves, for examples squared sections. Between the two sleeves a plurality of bearings are also advantageously foreseen suitable for allowing the relative sliding of the sleeves.

In a further alternative embodiment, the transmission of
35 the motion from the chuck to the preform is realised

through a magnetic device comprising at least one permanent magnet integral with the first sleeve and at least one magnet integral with the second sleeve.

The apparatus of the present invention can advantageously
5   be used both in chemical deposition processes with horizontal configuration (longitudinal axis X-X of the elongated element arranged horizontally) and in processes with vertical configuration (longitudinal axis X-X of the elongated element arranged vertically).

10 In the case of horizontal process configuration, the apparatus preferably comprises two opposite sliding elastic constraints associated with opposite end portions of said elongated element. The presence of elastic elements in correspondence with the two opposite ends of the elongated
15 element, in horizontal process configuration, is particularly preferred in the specific case in which traction or compression springs are used as elastic elements; such springs are placed in stretched condition (in the case of a traction spring) or compressed condition
20 (in the case of a compression spring), between the two coupling elements of respective elastic constraints; the two springs thus apply a reciprocal action such as to avoid that they can discharge (in such a case it would be impossible to realise the desired oscillation of the
25 elongated element). The elastic constant of the system is given in this case by the sum of the elastic constants of the two springs.

In an alternative embodiment of the apparatus of the present invention for a horizontal process configuration,
30 the apparatus comprises a single elastic constraint associated with an end portion of said elongated element, said elastic constraint being intended to work both by traction and by compression. Preferably, the elastic constraint shall comprise a spring bound at opposite sides
35 to the two coupling elements, so as to be able to apply

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both a thrusting elastic action and a pulling elastic
action of the elongated element. The elastic constant of
the system shall be given, in this case, by the elastic
constant of the single spring present in the single elastic
5   constraint of the apparatus.

Preferably, the apparatus in such a case comprises a
sliding guide associated with said elongated element on the
opposite side to said elastic constraint.

In the case of vertical process configuration, the
10 apparatus preferably comprises a single sliding elastic
constraint suitable for being associated with an end
portion of said elongated element. Advantageously, it is
possible to use a single elastic constraint since the
elastic element of such a constraint shall always be in
15 compressed condition (if the elastic constraint is
associated with the lower end of the elongated element) or
stretched condition (if the elastic constraint is
associated with the upper end of the elongated element) due
to the weight of the preform. The embodiment with a single
20 sliding elastic constraint in correspondence with the upper
end portion of the elongated element is preferred, for
example, in chemical deposition processes of the VAD type.
In chemical deposition processes of the OVD types, on the
other hand, the embodiment with a single elastic constraint
25 in correspondence with the lower end and with a sliding
guide in correspondence with the upper end, or vice-versa,
is preferred.

Preferably, the device for inducing the oscillation is
housed inside said at least one elastic constraint.

30 In a first embodiment thereof, the device for inducing the
oscillation comprises a pneumatic device acting upon said
second coupling element. In particular, said pneumatic
device comprises a small thrusting piston which, actuated
by compressed air, acts upon said second coupling element
35 loading the elastic element of the elastic constraint; by

discharging the air the elongated element starts oscillating about the position of equilibrium of the elastic element.

In a second preferred embodiment thereof, the device for inducing the oscillation comprises an electromagnetic device acting upon said second coupling element. In particular, the electromagnetic device comprises a solenoid arranged outside of the second coupling element and a permanent magnet integral with said second coupling element. The supply of current into the solenoid produces the axial force on the second coupling element, loading the elastic element of the elastic constraint; by interrupting the supply of current the elongated element begins to oscillate about the position of equilibrium of the elastic element.

Alternatively, it can be thought of not to create a suitable device for inducing the oscillation and to exploit the oscillations induced on the preform by the chemical deposition machine itself; such a machine can indeed itself represent a device for inducing the oscillation on the preform.

Preferably, the device for detecting the frequency of oscillation comprises a device for detecting the position of said elongated element, suitable for generating a signal indicating said position, and a device for processing said signal to work out the frequency of oscillation of the elongated element.

Preferably, the device for detecting the position of said elongated element comprises a target intended to be rigidly associated with said elongated element and an optical measurer of the distance of said target.

Preferably, the optical measurer comprises an emission source of a luminous signal towards said target, a device for receiving the luminous signal scattered by said target

and a device for processing the luminous signal collected to generate an electrical signal representing the distance of said target.

In an alternative embodiment, the detection of the
5　frequency of oscillation is realised through a proximity sensor associated with said first coupling element and suitable for detecting the position in time of said second coupling element. In the case in which the elastic element is a spring, the same spring can advantageously be used as
10　proximity sensor, which is no other than a solenoid having an inductance that varies with elongation.

In a second aspect thereof, the invention regards a method for measuring the weight of a preform for optical fibres during a chemical deposition process for the formation of
15　the preform, characterised in that it comprises the steps of:
-　elastically constraining an elongated element constituting a chemical deposition substrate to a chemical deposition machine for the formation of the preform;
20　-　inducing an oscillation of said elongated element;
-　detecting the frequency of oscillation of said elongated element;
-　calculating the weight of the preform according to the detected frequency of oscillation.

25　Such a method allows all of the advantages highlighted above with reference to the weight measurement apparatus of the present invention to be achieved.

In a first embodiment of the method of the present invention, the step of inducing an oscillation of said
30　elongated element comprises the following steps:
-　supplying pressurised air, for a predetermined time, inside a seat housing an end portion of said elongated element;
-　discharging the air from said seat after said
35　predetermined time.

In a second embodiment of the method of the present invention, the step of inducing an oscillation of said elongated element comprises the following steps:

- supplying current, for a predetermined time, into a
5   solenoid arranged outside of and coaxially with a coupling element associated with said elongated element, such a coupling element comprising at least one permanent magnet;
- interrupting the supply of current after said predetermined time.

10 Preferably, the step of detecting the frequency of oscillation of said elongated element comprises the following steps:
- generating a signal representing the position in time of said elongated element;
15 - processing said signal to work out the frequency of oscillation of the elongated element.

Preferably, the step of generating a signal representing the position in time of said elongated element comprises the steps of:
20 - sending a luminous signal towards a target rigidly associated with said elongated element;
- collecting a luminous signal scattered by said target; and
- processing the collected luminous signal to generate an
25 electric signal representing the distance of said target.

In a third aspect thereof, the invention regards a chemical deposition machine for the formation of a preform for optical fibres, comprising:
- a frame intended to support along an axis X-X an
30 elongated element constituting a chemical deposition substrate for the formation of a preform;
- at least one burner intended to deposit a chemical substance for the formation of the preform on said substrate;
35 characterised in that it comprises an apparatus for

measuring the weight of the preform of the type described above.

Such a machine allows all of the advantages described above with reference to the weight measurement apparatus of the

5   present invention to be achieved.

In a fourth aspect thereof, the invention regards a chemical deposition process for the formation of a preform for optical fibres, characterised in that it comprises a step of measuring the weight of the preform, during the

10 chemical deposition, through the weight measurement method described above.

Further characteristics and advantages of the present invention shall become clearer from the following detailed description of some of its preferred embodiments, given

15 with reference to the attached drawings. In such drawings,
    - figure 1 is a schematic view of a chemical deposition machine for the formation of a preform, comprising an apparatus for measuring the weight of the preform in accordance with the present invention;

20 - figure 2 is an enlarged schematic view of a longitudinal section of a constructive detail relative to a first embodiment of a device for fixing the preform and of a device for transmitting the motion to the preform of the machine of figure 1;

25 - figure 3 is an enlarged schematic view of a cross section, taken along the section line A-A of figure 1, of an alternative embodiment of a device for transmitting the motion to the preform of the machine of figure 1;
    - figure 4a is an enlarged schematic view of a

30 longitudinal section of a further alternative embodiment of a device for transmitting the motion to the preform of the apparatus of figure 1;
    - figure 4b is an enlarged schematic view of a cross section of the device of figure 4a, taken along the section

35 line B-B;

- figure 5 is an enlarged schematic view of a further alternative embodiment of a device for transmitting the motion to the preform of the machine of figure 1;

- figure 6 is an enlarged schematic view of a first
5   embodiment of a device for inducing oscillation of the machine of figure 1 in the embodiment of figure 2;

- figure 7 is an enlarged schematic view of a second embodiment of a device for inducing oscillation of the machine of figure 1 in the embodiment of figure 2;

10 - figure 8 is an enlarged schematic view of an oscillation detection device of the machine of figure 1 in the embodiment of figure 2;

- figure 9 shows a graph which depicts the results obtained experimentally through a first series of tests;

15 - figure 10 shows a graph which depicts the results obtained experimentally through a second series of tests;

- figure 11 shows a graph which depicts the results obtained experimentally through a third series of tests;

- figure 12 shows a graph which depicts the results
20 obtained experimentally through a fourth series of tests.

In figure 1, a chemical deposition machine for the formation of a preform for optical fibres is indicated with 1, including an apparatus 10 for measuring the weight of the preform during the chemical deposition process, in
25 accordance with the present invention.

The machine 1 illustrated in figure 1 is a machine with a horizontal attitude (axis X-X of the chemical deposition substrate arranged horizontally) and is suitable for realising a chemical deposition through a process of the
30 OVD type (Outside Vapor Deposition). Although the present description shall be made with reference to such a machine, that which is said hereafter and in the subsequent claims also has analogous application for machines with a vertical attitude (axis X-X of the chemical deposition substrate
35 arranged vertically), unless something is explicitly stated to the contrary. In the same way, that which is said also

applies to machines suitable for realising a chemical
deposition process of a different type, such as a process
of the VAD type (Vapor Axial Deposition) or a process of
the MCVD type (Modified Chemical Vapor Deposition).

5   The machine 1 comprises a frame 2 equipped with opposite
rotatable chucks 3a, 3b, of the conventional type, suitable
for supporting, along an axis X-X, an elongated element 100
(hereafter also indicated with the term: cylindrical
support) constituting a chemical deposition substrate for
10   the formation of a preform. The chucks 3a and 3b are such
as to rotatably bind the cylindrical support 100 so as to
transmit rotary motion to it.

The machine 1 also comprises a burner 4, of the
conventional type, intended to deposit on the cylindrical
15   support 100 a chemical substance for the formation of a
preform, in particular a mixture of silicon and germanium,
or just silicon, in the form of oxides (SiO_2 e GeO_2), so as
to realise, at the end of the chemical deposition process,
a preform 200. On the opposite side of the burner 4 with
20   respect to the axis X-X, a suction hood 5 is foreseen
intended to collect and evacuate the chemical discharge
substances produced by the burner 4.

In the embodiment of the machine 1 illustrated in figure 1,
the burner 4 moves, during the chemical deposition process,
25   parallel to the axis X-X of the cylindrical support 100,
which in turn rotates about the axis X-X so as to expose
all of its surface to the burner 4. The hood 5 can be still
or can move parallel to the burner 4. That which is stated
hereafter, in any case, also has analogous application in
30   the case in which the burner 4 is fixed and the elongated
element 100, besides rotating about its own axis X-X,
displaces along such an axis so as to expose all of its
surface to the burner 4, or furthermore in the case in
which both the burner and the elongated element 100 move
35   along the axis X-X.

In accordance with the embodiment illustrated in figure 1, the rotary motion is transmitted to the chuck 3a through a belt mechanism 6, of the conventional type, actuated by an electric motor 7. Through the belt 6 the motion arrives at
5 a pulley 8 integral with a small shaft 9a supported on the frame 2 by suitable rolling bearings 90a and upon which the chuck 3a is rigidly mounted. On the opposite side, the chuck 3b is rigidly mounted on a small shaft 9b supported on the frame 2 coaxially with the small shaft 9a by
10 suitable rolling bearings 90b.

As an alternative to the belt 6 suitable entirely conventional motion transmission gears can be foreseen.

In the chemical deposition machine 1 the cylindrical support 100 is not rigidly associated with the chucks 3a,
15 3b, but rather is elastically associated, in correspondence with the opposite free end portions 100a, 100b, with opposite elastic constraints 11a, 11b, which, in turn, are rigidly associated with the chucks 3a, 3b.

The elastic constraints 11a, 11b are an integral part of
20 the apparatus 10 suitable for measuring the weight of the preform during the chemical deposition process. Such an apparatus (illustrated in figure 8) also comprises a device 110 for inducing an oscillation on said elongated element 100, a device 111 for detecting the frequency of said
25 oscillation and a device 112 for calculating the weight of the preform according to the detected frequency of oscillation. Such devices shall be described in detail in the rest of the present description.

Figure 2 shows in detail a constructive example of an
30 elastic constraint 11a of the apparatus 10 for measuring the weight of a preform (and of the chemical deposition machine 1 for the formation of the preform) according to the present invention.

The elastic constraint 11a is illustrated associated with

the chuck 3a of the chemical deposition machine 1 illustrated in figure 1. The elastic constraint 11a comprises a first coupling element 12a rigidly associated with the chuck 3a and a second coupling element 13a rigidly
5   associated with an end portion 100a of the cylindrical support 100. In the illustrated example, the first coupling element 12a is a sleeve and the second coupling element 13a is a gripping member of said elongated element 100. The gripping member 13a is housed inside the sleeve 12a and is
10 shaped like a piston, with a shank 131a housed in a sliding seat 132a formed inside the sleeve 12a, and a head 133a associated with the free end of the cylindrical support 100 through one or more nuts or pins 134. The gripping member 13a is in turn associated with the sleeve 12a through an
15 elastic element 14a extending along the axis X-X, in this specific example a compression spring extending coaxially and externally to the shank 131a of the gripping member 13a. In the shank 131a of the gripping member 13a a slot 15a is formed inside which a pin 16a is housed integral
20 with the sleeve 12a. The coupling between pin 16a and slot 15a is a purely sliding coupling, in the sense that the only relative movement allowed is that of the sliding of the pin 16a in the slot 15a. The pin 16a, when the sleeve 12a is actuated into rotation by the chuck 3a, forces the
25 gripping member 13a, and therefore the cylindrical support 100 associated with it, into rotation.

The structural configuration of the elastic constraint 11a described above is therefore such as to prevent the translations of the cylindrical support 100, with the
30 exception of that along the axis X-X, to prevent the relative rotation between chuck 3a and cylindrical support 100 about the axis X-X (so as to allow the transmission of the rotary motion from the chuck 3a to the cylindrical support 100) and to elastically restrain the axial
35 translation of the cylindrical support 100.

The elastic constraint 11a described above is therefore a

sliding elastic constraint with a single degree of freedom, i.e. such as to allow exclusively an oscillation of the cylindrical support 100 along the axis X-X inside the sleeve 11a about a position of equilibrium of the spring 5 14a.

The elastic constraint 11a also comprises a further sleeve 17a rigidly associated with the end portion 100a of the cylindrical support 100. The sleeve 17a is coaxially coupled with the sleeve 12a through the interposition of a 10 bearing 18a suitable for allowing the relative sliding between said sleeves along the axis X-X. The sliding coupling between sleeve 12a and sleeve 17a is therefore such as to guide the axial sliding of the cylindrical support 100 inside the sleeve 12a.

15 Between the sleeve 17a and the cylindrical support 100 a ball joint 19a suitable for countering possible imprecisions of the cylindrical support 100 is preferably foreseen.

The elastic constraint 11b is substantially identical to 20 the constraint 11a described above. The cylindrical support 100 is therefore elastically bound in correspondence with the opposite free ends 100a, 100b.

The springs 14 of the two elastic constraints 11a, 11b are preferably both compression or traction springs. They are 25 placed between the sleeve 12a and the gripping means 13a in such a way as to both be biased (in compressed condition, in the case of compression springs, or stretched state, in the case of traction springs) when the cylindrical support 100 is loaded onto the machine 1, so as to apply a mutual 30 elastic action.

Alternatively, it is possible to foresee a single elastic constraint 11a associated with an end portion 100a of said elongated element 100. Such an elastic constraint shall, in such a case, comprise a spring 14a bound on one side to the

sleeve 12a and on the opposite side to the gripping member 13a, so as to be able to apply upon the gripping member 13a both an elastic thrusting action and an elastic pulling action. Preferably, in correspondence with the opposite end

5   100b of the elongated element 100 a simple sliding guide is in such a case foreseen.

It should be noted that, in the case of a machine with a vertical attitude (axis X-X of the chemical deposition substrate arranged vertically) the sliding elastic

10   constraint associated with one of the two end portions of the cylindrical support can be replaced with a sliding guide without any elastic element. In such a process configuration it is indeed possible to eliminate an elastic constraint since the elastic element of the single elastic

15   constraint foreseen is always biased (in compressed condition, if the elastic constraint is foreseen in correspondence with the lower end of the elongated element, or in stretched condition if the elastic constraint is foreseen in correspondence with the upper end of the

20   elongated element) due to the weight of the preform. Such an elastic element, therefore, can never be discharged, a necessary condition for realising the axial oscillation of the cylindrical support.

It is possible to foresee numerous variants relative to the

25   system for transmitting the rotary motion from the chuck 3a, 3b to the cylindrical support 100 for chemical deposition.

For example, in a first variant, illustrated in figure 3, the rotary motion of the chuck 3a is transmitted to the

30   cylindrical support 100 realising, instead of the sliding coupling between pin 16a and slot 15a, a shape fitting between outer surface of the sleeve 17a rigidly associated with the cylindrical support 100 and inner surface of the sleeve 12a rigidly associated with the chuck 3a. In such a

35   case, the sections of the sleeve 17a and of the sleeve 12a

shall have non-circular symmetry, for example squared, or
hexagonal, as illustrated in figure 3. Between the two
sleeves a plurality of bearings 170 suitable for allowing
the relative sliding of the sleeves are advantageously
5   foreseen.

In a second variant, illustrated in figures 4a and 4b, on
the outer surface of the sleeve 17a and on the inner
surface of the sleeve 12a opposite edges are realised,
respectively indicated with 171 and 172 (for example four
10   equally spaced edges on each sleeve, as illustrated),
suitable for mutually cooperating in abutment during the
rotation of the chuck 3a, in such a way that the sleeve 12a
forces the sleeve 17a, and therefore the cylindrical
support 100, into rotation. Between the two sleeves, in
15   correspondence with a longitudinal portion upstream or
downstream of the one in which the edges 171, 172 are
formed, a plurality of bearings 173 are also foreseen
suitable for allowing the relative sliding between the two
sleeves. Further bearings 174 suitable for easing such a
20   relative sliding are foreseen between the edges 171 and
172.

In a further variant, illustrated in figure 5, the rotary
motion of the chuck 3a is transmitted to the cylindrical
support 100 realising, instead of the sliding coupling
25   between pin 16a and slot 15a, a magnetic transmission
between the sleeve 12a, integral with the chuck 3a, and the
gripping member 13a, integral with the cylindrical support
100. In such a case, inside the sliding seat 132a of the
sleeve 12a a permanent magnet 180 is rigidly mounted; in
30   the same way, in the outer surface of the free end portion
of the shank 131a of the gripping member 13a another
permanent magnet 181 is rigidly mounted. The magnetic
action between the two magnets realises the constraint in
rotation, in the sense that when the sleeve 12a rotates it
35   forces the gripping member 13a, and therefore the
cylindrical support 100, into rotation.

As already stated, the apparatus 10 of the present invention comprises a device 110 (figures 6, 7 and 8) for inducing an oscillation of the cylindrical support 100 during the chemical deposition process. Such a device is

5   preferably housed inside either of the two elastic constraints 11a, 11b, and is an integral part of such an elastic constraint.

In a first embodiment thereof, illustrated in figure 6, the device 110 is a pneumatic device comprising a small

10   thrusting piston 20 slidably housed in the sliding seat 132a of the sleeve 12a. Such a small piston 20 is actuated by pressurised air coming into the seat 132a through a suitable opening 21. Such an opening is formed on a cover 22 arranged in correspondence with the free end of the

15   sleeve 12a. The thrusting small piston 20, when actuated, cooperates with the shank 131a of the gripping member 13a, thrusting it to slide in the seat 132a of the sleeve 12a, loading the spring 14a; at the moment when the air pressure is discharged, the gripping member 13a (and therefore the

20   cylindrical support 100 rigidly associated with it) begins to oscillate about the position of equilibrium of the spring 14a.

In an alternative embodiment thereof, illustrated in figure 7, the device 110 for inducing the oscillation is an

25   electromagnetic device comprising a solenoid 30 rigidly associated with a stator 31 foreseen upstream of the chuck 3a. The solenoid 30 is coaxial to the shank 131a of the gripping member 13a, which in turn houses a permanent magnet 32. The passage of current into the solenoid 30

30   produces the axial force on the gripping member 13a loading the spring 14a; by interrupting the supply of current into the solenoid 30 the gripping member 13a begins to oscillate about the position of equilibrium of the spring 14a.

As illustrated in figure 8, the apparatus of the present

35   invention also comprises a device 111 for detecting the

frequency of oscillation of the cylindrical support 100 during the chemical deposition process. Such a device comprises, in particular, a device for detecting the position in time of the cylindrical support 100 and for

5   generating a signal representing said position, and a device for processing said signal to work out the frequency of oscillation of such a support.

In the embodiment illustrated in figure 8, the device for detecting the signal representing the position in time of

10 the cylindrical support 100 comprises a target 40 rigidly associated with the end portion 100a of the cylindrical support 100, and an optical measurer 41 suitable for measuring the distance of said target 40. In particular, the optical measurer 41 comprises an emission source (not

15 illustrated) of a luminous signal towards the target 40, a device (not illustrated) for receiving the luminous signal scattered by the target 40, and a device (not illustrated) for processing the collected luminous signal to generate an electric signal representing the distance of the target 40.

20 The measurer 41 is equipped with an output capable of transmitting the electric signal to a calculator 112 equipped with a data acquisition board intended to calculate the weight of the preform according to the frequency of oscillation detected.

25 As an alternative to the device described above it is possible to use other devices (not illustrated) for measuring the frequency of oscillation of the preform. For example, the detection of the frequency of oscillation can be realised through a proximity sensor associated with the

30 sleeve 12a and suitable for detecting the position in time of the gripping member 13a. As proximity sensor the same spring 14a can advantageously be used, which is no other than a solenoid with variable inductance with elongation.

In principle, since the frequency of axial oscillation ω

35 is linked to the oscillating mass M by the following

relationship:

$$M = \frac{k}{\omega^2}$$

where k is the elastic constant of the spring 14a, knowing the elastic constant K of the spring 14a and the frequency of axial oscillation of the preform 200 during the chemical deposition process means that the mass, and therefore the weight of the preform 200 in formation, is known.

Various methods for calculating the frequency of oscillation are possible. As an example one of these is described in detail.

Through the calculator 112 equipped with an acquisition board the electric signal coming from the optical measurer 41 is continuously analysed. The frequency of acquisition of the signal must be such as to be able to correctly describe the electric signal, for example it is sufficient for it to be greater than double the frequency of the signal. In this case the frequency of sampling is equal to:

$$\omega_{min} = 2 \cdot \sqrt{\frac{K}{M_{min}}}$$

where K is the elastic constant of the elastic system and M_{min} is the smallest oscillating mass, i.e. equal to the mass of the cylindrical support 100 at the start of the chemical deposition process. It should be noted that, in the case of a machine with a horizontal attitude, such as the one illustrated in the attached figures, the elastic system comprises two elastic constraints 11a, 11b, each equipped with a respective spring 14. Therefore the elastic constant of the system shall be equal to the sum of the elastic constants of the individual springs present in the two opposite elastic constraints 11a, 11b. On the other hand, in the case of a machine with a vertical attitude, if it is with a single elastic constraint, the elastic constant of the system shall be equal to the elastic

constant of the single spring foreseen in the single
elastic constraint of the apparatus.

Through a threshold system, the registering of the electric
signal is activated at the moment when the oscillation
5   starts; the registering is then extended for a determined
time (chosen experimentally in such a way as to be greater
than the damping time of the oscillation). The electric
signal can be well described by a function of the type:

$$S(t) = A \cdot e^{-\alpha t} \cdot \sin(\omega t + \Phi) + \Delta$$

10   therefore, through a non-linear regression calculation, it
is possible to estimate the parameters A, α, ϕ, Δ and
finally the frequency ω.

Given the frequency it is possible to evaluate the
oscillating mass through the relationship:

15
$$M = \frac{k}{\omega^2}$$

valid in the case of an ideal harmonic oscillator; in a
real situation it is preferable to carry out a calibration
of the system with known masses so as to experimentally
determine the relationship M=M(ω).

20   In further alternative embodiments, the other frequencies
of oscillation of the cylindrical support 100 as a rigid
body can be used, realising any of the other manners of
oscillation of the cylindrical support 100; in
correspondence with the six degrees of freedom of a rigid
25   body there are indeed three translational manners of
oscillation and three rotational manners of oscillation to
which respective frequencies of oscillation correspond.

In operation, with reference to the embodiment of the
chemical deposition machine 1 and the weight measurement
30   apparatus 10 illustrated in the attached figures 1 and 8,
the cylindrical support 100 for chemical deposition, with

the target 40 associated, is mounted on the machine 1 associating the respective free ends with the opposite elastic constraints 11a, 11b. The machine 1 is then activated to start off the chemical deposition process,

5   during which the cylindrical support 100 rotates upon itself and the burner 4 translates parallel to the cylindrical support 100 and deposits thereupon the chemical substances for the formation of the preform. The suction hood 5 eliminates the discharge gases produced by the

10   burner 4.

During the chemical deposition process a measurement of the weight of the preform which is gradually being formed is repeatedly carried out through the apparatus 10. For such a purpose, an oscillation of the cylindrical support 100 is

15   induced through the pneumatic device illustrated in figure 6 and described above (or alternatively through the magnetic device illustrated in figure 7 and also described above).

Through the optical distance measurer 41 a luminous signal

20   is sent onto the target 40 and then detected. The signal thus obtained represents the variable distance between target 40 and optical measurer 41 and, therefore, contains information relative to the frequency of oscillation of the preform.

25   The electric signal detected by the optical measurer 41 is then sent to the calculator 112, where it is processed to finally work out, for example according to the calculation method described above, the progression of the weight of the preform as the chemical deposition process advances.

30   EXAMPLES

Different series of experimental tests have been carried out to demonstrate the operation of the apparatus of the present invention. The tests conducted were the following:

1. Reproducibility tests (with non-rotating preform)

2. Tests with rotating preform

3. Tests with different axial distributions of the masses

4. Tests with different spring temperatures

The oscillation was caused generating an impulse capable of
forcing a displacement of the cylindrical support 100 of
about 5 mm with respect to the position of equilibrium. To
detect the frequency of oscillation a commercial laser
distance measurer, which can be acquired from the company
Keyance, was used.

Reproducibility tests

The first series of tests was carried out measuring the
frequency of oscillation of a preform, not rotating, to
which different known masses were added. For each value of
additional mass different tests were carried out to
evaluate the calibration curve of the system M=M(w) and the
degree of reproducibility of the measurements. The first
series of tests was carried out without adding any mass to
the preform. Three successive series of tests were carried
out for three different values of additional mass.

The tests were conducted with a machine with a vertical
attitude equipped with a single spring in correspondence
with the lower end of the preform. The elastic constant of
the spring was 1.6 kN/m. The starting mass of the preform
was Kg. 2.690 (without any additional mass), whereas the
end mass (mass of the preform plus maximum additional mass)
was Kg. 4.990.

The results of these tests are shown in the graph of figure
9, which represents the frequency of oscillation measured
as a function of the mass.

The calibration curve can for example be well described
through a cubic polynomial.

A first estimation of the frequency values obtained through

repeated tests using the same mass was made. Then an estimation was made for the different mass values.

The average standard deviation on the frequency estimation through repeated tests using the same mass is equal to
5   0.0116 Hz. Therefore it was proved that, through the repetition of even a small number of measurements, the average precision on the estimation of the weight can be very good.

Tests with a rotating preform

10 The second series of tests was carried out for the purpose of evaluating possible disturbances linked to the rotation of the preform. Different measurements were taken using the same weight of the preform at different rotation speeds.

The tests were conducted with a machine with a horizontal
15 attitude equipped with two springs in correspondence with the opposite ends of the preform. The elastic constant of the springs was 1.6 kN/m. The mass of the preform was kept constant and equal to Kg. 2.690.

The graph of figure 10 shows the results of these
20 measurements which demonstrate a substantial independence of the frequency of oscillation from the rotation speed of the preform. Indeed, we observed an increase in the standard deviation of the measurements, which however keep the same average value.

Tests with different axial distributions of the
25
masses

The third series of tests was carried out for the purpose of demonstrating that the method for measuring weight of the present invention is substantially independent from the
30 distribution of the masses along the axis of the preform.

Two series of measurements using the same additional mass were conducted:

- with additional weight in correspondence with one of the ends of the preform;
- with additional weight in correspondence with the opposite end of the preform.

5   The tests were conducted with a machine with a horizontal attitude equipped with two identical springs in correspondence with the opposite ends of the preform. The elastic constant of the springs was 1.6 kN/m. The preform was not made to rotate. The starting mass of the preform

10 was Kg. 2.690 (without any additional mass), whereas the additional mass (first on one side and then on the other) was Kg. 0.762.

The two series of tests, shown in figure 11, do not outline significant differences in the average value.

15   Tests with different spring temperatures
The fourth series of tests was carried out for the purpose of demonstrating the insensitivity of the weight measurement method of the present invention to temperature, in particular to the presence of thermal gradients on the

20 structure. Different measurements were taken as the temperature of an air jet directed onto one of the two elastic constraints varied. The thermal field which generates in this way has the maximum and minimum temperature in correspondence with the extremes of the

25 elastic constraint under consideration, which is therefore subject to thermal gradients.

The tests were conducted with a machine with a horizontal attitude equipped with two identical springs in correspondence with the opposite ends of the preform. The

30 elastic constants of the springs was 5.15 kN/m. Just one of the two springs was biased. The preform was not made to rotate. The mass of the preform was kept constant and equal to Kg. 2.690.

The graph of figure 12 shows the results of these tests

which   demonstrate   the   actual   insensitivity   of   the
measurements with respect to the temperature.